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Field Performance of Open Graded Drainage Layers

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Abstract: The report presents the results of a field study carried out to investigate the performance of pavements incorporating open graded drainage layers (OGDLs). OGDLs are used to ensure rapid and effective drainage of pavement structures and thus to improve pavement performance. Altogether, five paving projects built since 1975 and incorporating OGDLs (Hwy 56, Hwy 3N, E.C. Row Expressway, Hwy 16N, and Hwy 7N) are described and evaluated. The projects encompass flexible, composite, and rigid pavements, and include both asphalt cement treated and untreated OGDL materials. The evaluation was done in terms of:

a) Pavement performance evaluation with emphasis, where possible, on comparing adjacent sections with and without OGDLs.

b) Occurrence and severity of major pavement distresses investigated by coring and trenching.

c) Assessment of in situ drainage done by observing movement of water within the pavement structure.

d) Laboratory analysis of excavated OGDL materials.

The results of this study show that the existence of OGDLs alone does not guarantee a better pavement performance. This can be achieved only if the OGDL is a part of a properly designed internal drainage system.

Comments: A final report on R&D project 21207 conducted in co-operation with the Royal Military College of Canada and Queen's University.

Key Words: pavement materials, aggregate, drainage layer, subdrains

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1/ Introduction

1.1/ Background

Excess water trapped in the pavement structure can accelerate pavement damage and cause premature pavement failure. In order to remove the excess water, a number of highway agencies have built or are experimenting with free draining layers or blankets using permeable granular materials [1,2,3]. This permeable layer is placed between the pavement surfacing materials and the subgrade and is referred to herein as an open graded drainage layer (OGDL).

Since 1975, the Ministry of Transportation, Ontario (MTO) has incorporated OGDLs into a number of different paving projects encompassing flexible, rigid and composite pavements. Six of these projects were built before 1989; additional three or four projects have been built since or are under construction. The objective of this report is to review our experience with the six older projects and evaluate the influence of OGDLs on pavement performance. The purpose of this work is twofold:

a) To provide feedback for pavement design practices incorporating OGDLs [4]. For example, to assess the need for OGDLs, their placement, and physical properties including gradation and protection of OGDLs from infiltration and clogging.

b) To determine if the function and performance of OGDLs can be predicted using the existing design procedures.

1.2/ Learning From the Past

The most recent OGDL project evaluated herein was built in 1987 and was probably designed one or two years before. Since then, our design practices and understanding of what constitutes an appropriate pavement subdrainage design have changed considerably. For example, in the past, the OGDLs were usually not connected directly to longitudinal subdrains, while current designs ensure a direct connection between the OGDL layer and longitudinal subdrains. The question can be posed: Why study the performance of pavement subdrainage designs which are old and are unlikely to be built again?

The reason for studying the performance of old designs is that we can always learn by evaluating and verifying our theoretical understanding of material behaviour and pavement performance using field

observations. While the materials of drainage layers and their arrangement can always change, the basic design principles are universally applicable and change only if they do not adequately explain what happens in the field. In other words, we are studying the field performance to verify our design principles. Also, we should realize that our current subdrainage pavement designs may be frowned upon in 5 or 10 years. This does not prevent us from designing and constructing them now and it should not prevent us from evaluating the performance of the past designs.

1.3/ General Considerations in Subdrainage Design

Pavement systems, particularly those containing granular base and sub-base materials, should not contain free, gravitational water (which moves because of gravitational force). If free water is present, the effects of dynamic traffic loading can lead to pumping (movement of free water and suspended aggregate particles underneath two adjacent pavement slabs) and to premature loss of riding quality. There is also a concern with the loss of stability due to high pore pressures in saturated dense graded aggregate layers.

Well constructed pavement surfaces on provincial highways which are without cracks are practically impervious. The water reaching the granular layers and subgrade comes mainly from the following sources:

a) Water infiltration through cracks in the pavement surface (a typical number, given in Reference 5, is 0.22 m^3 per day per metre of crack).
b) Capillary and gravity flow of groundwater.
c) Melt water from ice lenses.

It is possible to quantitatively estimate the amount of free water infiltration into the pavement structure and to design a subdrainage system sufficient for its rapid removal. Reference 5 provides a step by step procedure, as well as a number of solved examples, for highway subdrainage design. The major design considerations include the following:

1.3.1/ Permeability of OGDL

The recommended permeability for OGDLs carrying water across a pavement roadbed on a 2 or 3 percent slope is typically above 0.17 cm/s (500 ft/day) [1]. Reference 6 implicitly recommends 0.35 cm/s (1000 ft/day). At any rate, the typical gradation curves for OGDL materials used on past Ministry projects,

plotted in Figure 1 together with several theoretical gradation curves, indicate that our materials meet and significantly exceed the recommended permeability criteria.

1.3.2/ Thickness of OGDL

An appropriate combination of layer thickness, permeability and (hydraulic) gradient is required to remove rapidly infiltrated water from the pavement structure. Considering construction tolerances and the potential for contamination, the minimum thickness is usually 75 mm.

1.3.3/ Collection System

The purpose of the collection system is to collect and remove the water carried by the drainage layer towards the pavement edge. The design of the collection system (i.e. dimension and placement of lateral subdrains and outlets) and the design of the drainage layer are interdependent.

1.3.4/ Protection System

OGDLs and the collection system subdrains must be protected from intrusion of fines by appropriate granular or geotextile filters. Pumping action caused by repetitive traffic loads is notorious for initiating intrusion of fines into the pores of a granular material.

2/ Field Evaluation of OGDLs

This section describes pavement structure and subdrainage design of the six projects incorporating OGDLs and evaluates their performance. The evaluation is done in terms of:

a) 1990 pavement performance evaluation, with emphasis, where possible, on comparing the performance of the adjacent pavement sections with and without OGDLs.

b) Occurrence and severity of major pavement distresses investigated by taking 150 mm diameter cores and by trenching.

c) Assessment of in situ drainage done by observing movement of water within the pavement structure.

d) Laboratory analysis of OGDL materials obtained by coring and/or excavating. The analysis included tests for asphalt cement (AC) content (ASTM D 2172), grain size distribution (ASTM C 127-84), bulk density (ASTM 1188-83), and other routine tests. The results are summarized in Reference 7. Only some selected results are given in this report.

The main characteristics of the six projects incorporating OGDLs are summarized in Table 1.

2.1/ Highway 56

The experimental OGDL site is located about 80 m south of the intersection with Hwy 20. The basic characteristics of the project are summarized in Table 1 and further details are available from Reference 8 and from contract drawings (referenced in Table 1).

2.1.1/ Pavement Design and Method of Drainage

The site encompasses four sections: three test sections with OGDLs and a control section without an OGDL (Table 2). It may be noted that all four sections have the same design thickness of asphalt concrete (130 mm). However, based on the field investigation by coring and trenching, it appears that the actual asphalt concrete thickness is somewhat higher on sections with untreated OGDLs. This may be attributed to the unevenness or distortion of the untreated OGDLs prior to paving.

The untreated OGDLs were placed full width across the roadbed with daylighting at the ditch slopes below the shoulder rounding. The treated OGDL was placed below the pavement only and, in this case, the untreated OGDL was placed on the remaining portion of the roadbed below the shoulders and again daylighted. Where possible, OGDLs were placed on a 3% crossfall.

2.1.2/ Pavement Performance Evaluation

After 15 years of service (the project was constructed in 1975 as shown in Table 1), all four sections exhibit quite similar performance, both in terms of Riding Comfort Rating (RCR = 6.0) and the occurrence and severity of pavement surface distresses. The main distress (on all sections) is frequent severe full width transverse cracking (Figure 2). All sections received the same pavement maintenance, namely routing and sealing, probably in 1982. The transverse cracks are often cupped (the depression is about 12 mm on 300 mm straightedge), are starting to become multiple (transverse cracks) and some begin to alligator. Sealant bond failure is quite frequent.

The exception to "quite similar performance on all four sections" occurs at the south end of Section 4 (150 mm thick untreated OGDL), southbound lane, which has also block cracking and centre line alligator cracking (Figure 3). This part of Section 4 is on a vertical sag curve and is also superelevated towards the southbound lane. The lack of positive crossfall drainage at this location may cause ponding of water on the granular base inside the OGDL and contribute to settlement and structural weakness of the pavement.

2.1.3/ Distress Investigation by Coring and Cutting

The investigation by coring (taking 150 mm cores) and cutting (cutting 600 x 250 mm slabs from the pavement surface as shown in Figure 2) focused on transverse cracks. Transverse cracks are the main distress and the major reason for upcoming pavement rehabilitation. About three or four cores were taken on each section through uncracked, undamaged slabs, and in the vicinity of cracks, and through cracks. The cuts were made only across the transverse cracks, one or two per section.

The OGDL material obtained at locations far from cracks appeared to be undamaged and dry. The AC treated OGDL material (Section 3) was usually recovered in one piece and was bonded to the overlaying asphalt concrete. Its AC content was close to the 3% value specified for this section (see Table 3). A quite different situation was observed near transverse cracks where the OGDL material was wet and contaminated with fines from the base material (Granular A).

A composite representative condition of transverse cracks based on coring and cutting is shown in Figure 4. It appears that the existence of OGDL had no significant influence on the frequency of transverse cracks, or on the condition of transverse cracks in terms of crack opening, asphalt concrete stripping at the bottom of the asphalt concrete layer, or cupping. There was noticeable stripping of asphalt cement from the aggregate particles of the treated OGDL material. A low value of 1.3% AC was obtained from

a sample taken below a fully developed transverse crack. Otherwise the type and the area of contamination with fines and the amount of fines in the OGDL materials was quite similar on all three OGDL sections.

2.1.4/ Investigation of In Situ Drainage

The investigation of the internal drainage of the pavement structure concentrated on the following parameters.

2.1.4.1/ Daylighting of OGDL

The topsoil on the ditch slope was removed at several locations to examine the condition of the OGDL material. The top soil cover was about 300 mm thick. The OGDL was distinguishable from the surrounding layers of Granular A material even though it was contaminated with top soil and Granular A material. Underneath the shoulder, the OGDL material was less contaminated and appeared to be free draining.

2.1.4.2/ Crossfall Drainage

Water was poured into a 600 x 250 mm cut in the asphalt concrete and the OGDL material and its propagation towards the ditch was observed using two additional openings between the cut and the ditch daylighting. As indicated by the results given in Figure 5, the crossfall drainage appeared to be sufficient at the location investigated.

2.1.4.3/ Permeability

Water was poured into the core holes and cuts and the drop in the water level was observed. The areas of contamination shown in Figure 4 drained very slowly. Usually, there was no observable water drop in 10 minutes. Non-contaminated areas drained so fast that no water head could be maintained using a 25-litre container.

2.2/ Highway 3N

The pavement section with an OGDL on Hwy 3N is part of a large 1982 experiment investigating the design, construction and performance of plain-jointed Portland cement concrete (PCC) pavements. The experiment encompasses four different pavement designs including one design with an OGDL (Table 1). The design and performance of all four pavement sections is described in detail in References 9 and 10 and will be only briefly reviewed herein.

2.2.1/ Pavement Design and Method of Drainage

The pavement structure of the four sections is summarized in Figure 6 and the arrangement of the OGDL section is shown in Figure 7. The OGDL was placed directly on a silty clay subgrade, and longitudinal drain pipes (installed on all four sections) were plowed in and backfilled with the excavated shoulder material. The highway grade in the vicinity of the OGDL section is mainly at grade.

2.2.2/ Pavement Performance Evaluation

A detailed pavement performance evaluation of all four pavement test sections was conducted after three years of service [9] and after six years [10]. Briefly, all four PCC sections have roughly similar pavement roughness. However, the OGDL section and the section with full depth PCC have considerably less cracking distresses than the remaining two sections with lean concrete bases (Figure 7). It is interesting to note that:

a) the OGDL section is less expensive than the full-depth section but provides a comparable performance, and

b) the structural strength of the OGDL section is lowest of the four.

The major distresses on the OGDL section are faulting of transverse joints and corner cracking. The transverse joints are stepped, on the average, by about 3 mm. The maximum stepping is about 8 to 12 mm.

2.2.3/ Distress Investigation by Coring

While the OGDL section is 5.2 km long, the portion investigated by coring spanned only about 75 m and exhibited larger than average faulting. Five cores were taken on the OGDL section at undamaged locations far from cracks and joints, at the vicinity of joints and cracks and, through transverse joints. An additional core was taken at the shoulder near the pavement edge. The coring was done in June of 1989, following a night of heavy rainfall. Before the coring started, pumping action of traffic at transverse joints was clearly observed: small droplets of water were ejected from the joints by passing trucks and squirted upwards, making the pavement surface close to the joints wet and stained with clay and silt particles.

The cores taken at mid-slab vicinity (far from joints) revealed a well-preserved OGDL material. About 80% of the material was recovered from the 175 mm bit cylinder in one piece and was bonded to the PCC. It was observed that the OGDL material in the core holes was flooded with water and, soon after the core was removed, the water level rose to within 50 mm of the pavement surface. The bottom 20 mm layer of the OGDL material was contaminated with subgrade (silty clay) and was loose showing signs

of stripping. The AC content of the bottom portion of the core was 2.0% compared with 2.7% obtained for the top portion of the core.

The cores taken at transverse joints exhibiting faulting revealed loose, partly stripped OGDL aggregate (AC content ranged from 1.1% to 1.9%) heavily contaminated with subgrade material. The OGDL material in all core holes was flooded. There was no loss of material at the bottom on the PCC slabs. Figures 8 and 9 contrast the condition of the OGDL material obtained at a mid-slab location with that close to a joint.

2.2.4/ Investigation of In Situ Drainage

Approximately 12 hours after a heavy rainfall, the OGDL was saturated with water at the locations investigated. There was no noticeable drop of the water level during an hour. The single core taken from the shoulder close to pavement edge revealed that the OGDL aggregate was completely plugged with clay fines and to a large extent mixed with the shoulder Granular A material.

It appears that the water ponding in the OGDL is caused by relatively impervious granular materials separating the OGDL from the lateral drains and ditch daylighting (Figure 7). Another contributing factor to ponding may be a low hydraulic gradient of the lateral subdrains which are covered with a geotextile material protecting the perforated plastic subdrain from contamination.

Drain outlets of the lateral subdrains located on the ditch slopes were in good condition, relatively clean and free of vegetation. Most of them were discharging water but not in the amounts expected. The rate of water discharge from the outlets seemed to be the same on all four sections. The OGDL section, as well as the other sections, will benefit from retrofitting with pre-manufactured edge drains. In the case of the OGDL section, the edge drains should cut through the OGDL and reach the top of the subgrade.

2.3/ E.C. Row Expressway in Windsor

Two OGDL pavement sections were built in 1982 on the E.C. Row Expressway, near Dominion Blvd. and near Huron Church Road, to carry the expressway over these two local streets (Table 1). Both OGDL sections are mainly on a high fill and are younger than the adjacent pavement structures, which are mainly at grade. For this reason it is not constructive to compare the performance of the OGDL sections with that of the adjacent pavement structures.

2.3.1/ Pavement Design and Method of Drainage

The same composite pavement design, shown in Figure 10, was used for both locations. The OGDL material was placed on the fullwidth of the roadbed with daylighting at ditch slopes. The asphalt cement treated OGDL material was placed underneath the pavement and extended 600 mm beyond the edge of pavement; the untreated material was placed underneath the remaining width of the shoulder.

2.3.2/ Pavement Performance Evaluation

The pavement performance of the two OGDL sections is similar. Riding comfort rating is 8.5 and the predominant distress are full-width slight transverse cracks reflected above contraction joints which were pre-cut in the plain PCC base. The transverse cracks have reflected above nearly all contraction joins resulting in 3 to 6 m spacing. Some of the cracks are starting to spall, particularly on driving (truck) lanes (Figure 11). No crack stepping was measured, however, some rocking of the slabs was noticeable between two adjacent slabs separated by a spalled transverse crack when loaded trucks were passing.

2.3.3/ Distress Investigation by Coring

The majority of cores were taken in the vicinity of transverse cracks. One core was taken near the middle of the (paved) right shoulder. The results of coring are shown in Figure 12. In many respects the results are similar to those observed on Hwy 3N. The OGDL material at locations far from transverse cracks was in a very good condition with little or no stripping and some contamination by the subgrade material at the bottom. The level of contamination and stripping increased with closeness to transverse cracks. There was no loss of PCC material at the bottom of the PCC base near the contraction joints.

2.3.4/ Investigation of In Situ Drainage

2.3.4.1/ Daylighting

The removal of granular material and topsoil on the ditch slope (i.e. digging of daylighting test holes) revealed a well-preserved layer of the OGDL material (Figure 13). At the daylighting test holes close to transverse cracks, the OGDL material was quite wet and the underlying subgrade material was saturated. It appears that water is entering pavement structure through cracks and is drained through the OGDL.

2.3.4.2/ Crossfall Drainage

Water was poured into 150 mm core hole drilled in the middle of the paved shoulder. The rate of water dissipation was quite high (see results in Table 3 for core hole 3), but because of the overall wet subgrade condition and the 3% longitudinal pavement grade, it was not possible to observe additional water seepage at the daylighted test hole(s). The sketch of core hole 3 in Figure 12 also shows uneven thickness of the untreated OGDL beneath the shoulder and some minor contamination.

2.3.4.3/ Permeability

The in situ permeability was tested by pouring water into core holes and measuring the rate of water dissipation. The data in Table 3, together with the results of coring given in Figure 12, suggest that only the top portion of the OGDL was free draining in the vicinity of transverse cracks. Because of heavy contamination with subgrade fines, the bottom portion of the OGDL was quite impervious.

The two OGDL sections will benefit from an early routing and sealing of transverse cracks, which should prevent free water from entering the pavement structure. Routing and sealing should also arrest the incipient spalling of transverse cracks.

2.4/ Highway 16N

The section incorporating the OGDL is one of the three different pavement structures built under Contract 84-22. The OGDL section is 1 km long (Table 1) and is located roughly in the middle of a 6 km long section using a modified granular design (Figure 14). The third section is 6.7 km long, has a conventional flexible pavement design, and is adjacent to the south end of the modified granular design section.

2.4.1/ Pavement Design and Method of Drainage

The design of the three pavement structures is shown in Figure 14. The lateral drainage of the OGDL section depends on subdrains placed below the pavement edge. According to contract drawings, the subdrains were supposed to be placed atop the subgrade. The actual placement is higher in the pavement structure: in Granular A material just below its top surface which was primed with an asphalt emulsion and sanded.

2.4.2/ Pavement Performance Evaluation

The roughness of all three sections, as reported on pavement condition evaluation forms, is quite similar

(riding comfort rating is about 8.5) while the pattern of cracking distresses is somewhat different. In addition to slight longitudinal cracks (midlane, centre line, and wheel track cracks), which are on all three sections, the conventional section has noticeably higher density of these cracks and has also a few slight half and full transverse cracks. It was also reported that pavement roughness on the OGDL and modified granular design sections does not increase during winter while it is noticeably higher on the conventional design section.

Some of the longitudinal cracks on the OGDL and the modified granular design sections were routed and sealed in 1987. It is still too early to estimate the difference in the lifespan of the three designs. Nevertheless, in addition to its better performance, the OGDL section has also lower Granular Base Equivalency (GBE) thickness (588 mm) than the conventional section (660 to 685 mm) and was less expensive to construct. The calculation of the GBE thickness assumed that the GBE factor of the OGDL material is equal to one.

2.4.3./ Investigation of Distresses by Coring

The coring revealed undamaged OGDL material even if the cores were taken at (longitudinal) cracks. The OGDL material was usually well bonded to the bottom of the asphalt concrete layer. The primed and sanded surface of the Granular A material (Figure 14) appeared to be undamaged and in very good condition.

Based on seven cores, the thickness of the asphalt concrete material above the OGDL ranged from 80 to 110 mm. The thickness of the OGDL ranged from 70 to 110 mm and its AC content varied from 1.3 to 2.0%. Below the shoulder, where the OGDL material was more exposed to moisture, the AC content ranged from 0.7 to 1.1%. Based on tests conducted on 5 cores, the average bulk density was 1852 kg/m^3 with the range of 1791 to 1894 kg/m^3. There was no obvious reason for the spread in the bulk density values that could be related to sample location.

2.4.4/ Investigation of In Situ Drainage

2.4.4.1/ Daylighting and drainage outlets

Drainage outlets appear to be inactive and do not discharge water.

2.4.4.2/ Crossfall Drainage

Water was poured into core holes in the pavement and its progression towards the ditch was observed by using test pits dug in the granular shoulder. The sketch of the experiment given in Figure 15 shows that the crossfall drainage was impeded. The OGDL material is abutted by Granular A material and the longitudinal subdrains are separated from the OGDL by the primed and sanded surface of the Granular A layer.

2.4.4.3/ Permeability

No significant water head could be established when water from 25-litre containers was poured into 150 mm core holes. It appears that water dissipated very quickly by ponding on the primed and sanded surface of the Granular A layer.

2.4.4.4/ Subgrade Moisture Content

The effect of the OGDL on reducing the moisture at the pavement-subgrade interface was evaluated by TRD-type moisture gauges [11] installed during construction on all three sections. The gauges were installed on the top of the subgrade (a) below the edge of pavement and (b) below the centre line of the northbound lane. The measured moisture levels given in Figures 16 and 17 indicate that the presence of the OGDL may have somewhat reduced subgrade moisture content. However, it should be noted that (a) the moisture measurements using TRD instrumentation are experimental, (b) only the OGDL and modified granular design sections were placed on a primed and sanded base and, (c) ground water regimes may be different at the three far-spaced sections.

2.5/ Highway 7N

The pavement test site on Hwy 7N encompasses, in addition to four conventional flexible pavement test sections, a 150 m long test section incorporating an OGDL [12]. The cross-sectional design of the OGDL section, shown in Figure 18, is unusual. A last-minute change in shoulder design resulted in building a curb at the pavement edge which interrupts the flow of water in the OGDL towards the ditch line. For this reason, the OGDL pavement section on Hwy 7N is included in this report mainly for completeness.

2.5.1/ Pavement Performance Evaluation

A comparison with the adjacent conventional pavement structure shows no significant differences in pavement performance attributable to the presence of the OGDL. This conclusion should be viewed in the light of the following two observations:

a) The OGDL section has a considerably lower granular base equivalency (GBE) thickness than the adjacent pavement section: 480 mm versus 700 mm, a difference of about 40%. (505 mm assumes that the GBE factor of the OGDL material is equal to one, and uses an as-built asphalt concrete thickness of 140 mm; 700 mm is based on 140 mm of asphalt concrete, 150 mm of Granular A, and 400 mm of Granular B.)

b) All sections are covered with a 40 mm layer of a dense friction course (DFC) containing steel slag aggregate. The layer exhibits extensive slight block cracking and ravelling which is often considered endemic to this material and tends to mask a difference, if any, in the performance of the individual sections.

2.5.2/ Distress Investigation by Coring

Six cores were taken from the OGDL section, some of them through (block) cracks exhibiting the highest severity. The cracks were confined to only the DFC layer and the layer was not usually bonded to the underlying asphalt concrete layer. The OGDL material was bonded to the bottom of the asphalt concrete and, with one exception, was retrieved in one piece. There was no intrusion of fines in the OGDL material.

The thickness and gradation of the OGDL material were as specified. Based on four cores, the mean value of AC content was 1.9% with the range of 1.5 to 2.3%. Based on five cores, the average bulk density was 1847 kg/m^3 with a range from 1817 to 1863 kg/m^3.

3/ Application of Design Principles

3.1/ Intrusion of Fines

One of the major problems limiting the performance of OGDLs, identified by the field investigation on Hwys 56, 3N, and the E.C. Row Expressway, was clogging of the OGDL material with fines. Movement of the fine soil particles can be caused by the movement of water from a fine grained soil (such as subgrade clay) to the OGDL, by the pumping action of repetitive axle loading, and by penetration of the coarse OGDL material into a fine grained material during the period of spring thaw. Generally recommended criteria for the design of protective granular filters, summarized in Table 4, are used in this section for after-construction prediction of the clogging phenomenon.

3.1.1/ Protection of OGDL from Intrusion of Fines from Subgrade

This case considers the arrangement, similar to that existing on Hwy 3N and on the E.C. Row Expressway, where the OGDL is placed directly on a clay subgrade. Representative gradation curves for the OGDL material and a silty clay subgrade are given in Figure 19. Also shown as arrows in Figure 19 are gradation criteria for a granular filter. The filter criteria were obtained by substituting the appropriate subgrade gradations into the equations of Table 4. The gradation range of the OGDL material is completely outside the filter criteria and it is obvious that a filter layer should be provided to protect the OGDL from clogging. Consequently, in the absence of a filter layer, the observed intrusion of fines in the field is to be expected.

Figure 19 also gives a gradation range for Granular A material. The gradation of Granular A material satisfies the filter requirements for the protection of the OGDL from intrusion of fines from the subgrade and can be thus considered to be a filter. It now remains to be checked if the OGDL material needs protection from intrusion of fines from the Granular A material. This is done separately in the following section.

3.1.2/ Protection of OGDL from Intrusion of Fines from Granular A Material

This case considered the arrangement, similar to that existing on Hwy 56, where the OGDL is placed atop Granular A material. Typical gradation curves for OGDL and Granular A materials, as well as the corresponding filter criteria obtained by substituting Granular A gradations into equations of Table 4 are given in Figure 20. The filter criteria (shown as arrows) overlap the gradation range of the OGDL material. The generally recommended filter criteria are satisfied and no filter is required. However,

field observations suggest otherwise: the OGDL was clogged near the transverse cracks where pumping action of traffic took place. This suggests that caution must be exercised when using the filter criteria given in Table 4 where pumping is a possibility.

In addition to granular filters, other measures to reduce the occurrence of clogging include curtailing the amount of fines in the granular base material, priming and sanding the top of the granular base, and the use of geotextile filters.

3.2/ Collection System

Another major problem limiting the performance of OGDLs was inadequate collection system for rapid removal of water carried by the OGDL toward the pavement edge.

In the case of Hwy 56 and the E.C. Row Expressway, there is no collection system per se: the removal of water depends on daylighting below shoulder rounding. The lateral drainage through daylighting may be restricted by:

a) Contamination from overlaying granular shoulder materials and topsoil, and blocking by the layer of topsoil. The topsoil cover may be quite formidable on gentle slopes (4:1) such as those on Hwy 56 (Section 2.1.4.). On the steep slopes (2:1) of the E.C. Row Expressway sections, the top soil does not appear to hinder drainage (Figure 13).

b) Uneven and/or inadequate thickness of the OGDL. An example of uneven thickness is shown in Figure 12 (for Core 4).

c) Inadequate crossfall grade of the OGDL as documented in Figure 3.

It may be noted that some authorities [6], as well as the MTO current guidelines, do not recommend the use of daylighting for draining of the OGDLs.

In the case of Hwys 3N, 7N, and 16N, drainage collection systems are in place but the OGDLs are not directly connected to longitudinal subdrains. The high permeability of the OGDL material is not utilized if free water must overcome a relatively impervious barrier, for example formed by Granular A material, before it can reach lateral subdrains.

Inadequate collection system can allow water to collect in the permeable OGDL material and to remain there for a considerable time, and certainly longer than desirable. This water can enable the destructive synergistic action of traffic loads and free water, referred to as pumping, to take place.

4/ Conclusions and Recommendations

4.1/ General Conclusions and Recommendations

1. The existence of OGDLs as such does not automatically guarantee an improved pavement performance. To achieve it, we need a comprehensive internal drainage design harmonizing the use of OGDLs (in terms of permeability, thickness and crossfall gradient), a collection system (dimensions and placement of subdrains and outlets), and a protection system (type and placement of filters).

2. High permeability OGDLs are susceptible to clogging by fines when they are subjected to pumping at cracks and working joints by repeated traffic loads, particularly if the collection system and/or the filter system is inadequate and free water is allowed to linger in the OGDL material. Generally accepted filter criteria may not be sufficient to protect high permeability OGDL materials from clogging under these circumstances.

3. Monitoring of the performance of pavement sections incorporating OGDL materials should continue along the lines outlined in this report.

It should be noted that the recent MTO designs and specifications for OGDLs address the design inadequacies described in this report.

4.2/ Site Specific Conclusions

4.2.1/ Highway 56

The existence of OGDLs has had no significant influence on the performance of the asphalt concrete pavement after 15 years of service. The major distress, transverse cracking, has similar characteristics on the sections with and without the OGDLs in terms of crack frequency and crack condition (crack opening, asphalt cement stripping on the bottom of the asphalt concrete layer, and cupping). In the vicinity of transverse cracks, the OGDLs were quite impervious and clogged with fines, at other locations the OGDLs were free draining.

4.2.2/ Highway 3N

All four PCC sections have similar pavement roughness after 8 years of service. However, the section with the OGDL and the section with full depth PCC show considerably less cracking distress than the remaining two sections. Overall, the permeability of the OGDL was restricted by relatively impervious granular materials separating it from the lateral drainage collector system. At faulting transverse joints, the OGDL material was loose and intermixed with subgrade clay. The OGDL section will probably benefit from retrofitting with pre-manufactured edge drains cutting through the OGDL and reaching the top of the subgrade.

4.2.3/ E.C. Row Expressway

It is not possible to compare the two composite pavement sections incorporating OGDLs with adjacent pavement structures. The OGDL material at locations far from transverse cracks was in very good condition with some contamination by the subgrade material at the bottom. The level of contamination and stripping increased with the closeness toward the transverse cracks. At the cracks, only 1/4 of the OGDL was free draining. The pavement will benefit from an early routing and sealing of transverse cracks which should prevent free water from entering the pavement structure. The routing and sealing should also arrest the incipient spalling of transverse cracks.

4.2.4/ Highway 16

Overall, after 6 years of service, the performance of the OGDL and the modified granular design sections is better than that of the conventional section even though the conventional section has the highest Granular Base Equivalent (GBE) thickness. The OGDL material is well preserved but the capacity of the lateral drainage system is low and is not compatible with the high permeability of the OGDL.

4.2.5/ Highway 7N

The OGDL section is included in this report mainly for completeness because of the clearly recognizable idiosyncrasies of the pavement design. Yet, after 5 years in service, it performs as well as the adjacent section with a conventional pavement structure with a 40% higher GBE thickness.

Acknowledgements

The authors wish to acknowledge the effort of all those who designed and constructed the pavement test sections investigated in this report. Their efforts and foresight made this report possible. Valuable comments and information were received from Sam Cheng. Field work was greatly assisted by Messrs M. Stott and A. Weremi.

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Table 1/ MTO projects incorporating open-graded drainage layers

Location	Date of Constr.	Contract No.	89 Traffic Volume (AADT)	No. of Traffic Lanes	Pavement Structure	Length of ODGL Sect. (m)	Asphalt Content of ODGL (%)	Thickness of OGDL mm
Hwy. 56, south of Elfrida	1975	75-02	8400	2	Flexible	122	0	75
				2		122	3	75
				2		122	0	150
Hwy. 3N, west of Leamington	1982	82-01	8500	2	Rigid	5200	2	100
E.C. Row near Dominion Blvd.	1987	87-37	25000	4	Composite	500	2	100
E.C. Row, near Huron Church Rd.	1987	87-23	11000	4	Composite	300	2	100
Hwy. 16N, south of Ottawa	1984	84-22	11000	2	Flexible	100	2	100
Hwy. 7N, west of Bathurst St.	1985	84-85	27600	6	Flexible	150	2	100

Table 2/ Arrangement of test sections on Hwy. 56

Test Section	Thickness of pavement layers, mm			
	Asphalt Concrete		OGDL (Observed)[1]	Granular A (Design)
	Design	Observed[1]		
1. Control	130	140	0	535
2. 75 mm untreated OGDL	130	175	75	460
3. 75 mm A.C. treated OGDL	130	140	75	460
4. 150 mm untreated OGDL	130	175	150	385

1) Established by coring or cutting (trenching)
The total thickness of granular materials, considering OGDL to be a granular material, was 535 mm on all sections.

Table 3/ Permeability of OGDL, E.C. Row Expressway

Core Hole[1)]	Drop in Water Level, [2)] mm			
	Time Since Water Poured In, minutes			
	1	8	15	20
3	6	13	16	16
2	32	38	44	44
4	50	100	100	100

1) Refer to Figure 12.
2) Drop in the water level below the bottom of the PCC base.

Core Hole	Permeability, mm/s[1)]			
	Time Since Water Poured In, minutes			
	1	8	15	20
3	0.11	0.04	0.02	N/A
2	0.53	0.09	0.05	N/A
4	0.85	0.21	0.11	N/A

1) Average permeability during the specified time period

Table 4/ Filter criteria

(D_{15}) filter	$\leq 5\ (D_{85})$ protected soil	(1)
(D_{15}) filter	$\geq 5\ (D_{15})$ protected soil	(2)
(D_{50}) filter	$\leq 25\ (D_{50})$ protected soil	(3)
(D_5) filter	≥ 0.074 mm	(4)
(CU) filter	$= \frac{(D_{60})\ \text{filter}}{(D_{10})\ \text{filter}} \leq 20$	(5)

Notes: • Source: Reference 5

• The requirements of Equation 3 can be waived when the soil to be protected is a medium to high plasticity clay.

• The terminology of D_X represents the size of particle in mm which will have x percent of the material smaller than that size.

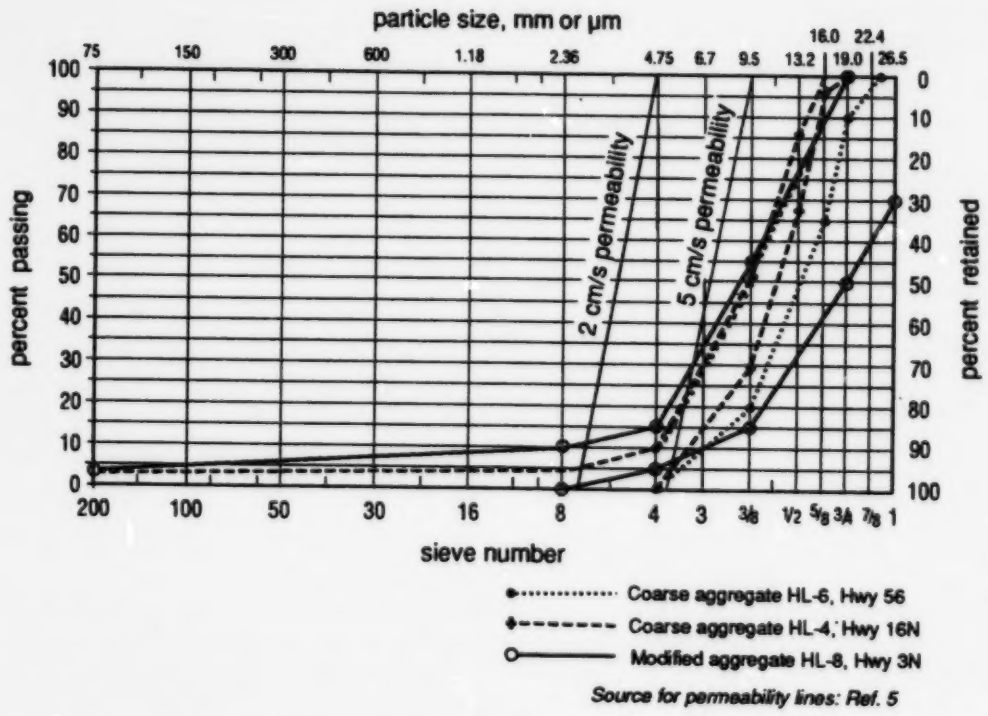


Figure 1/ Gradation curves and permeability of open graded drainage layers

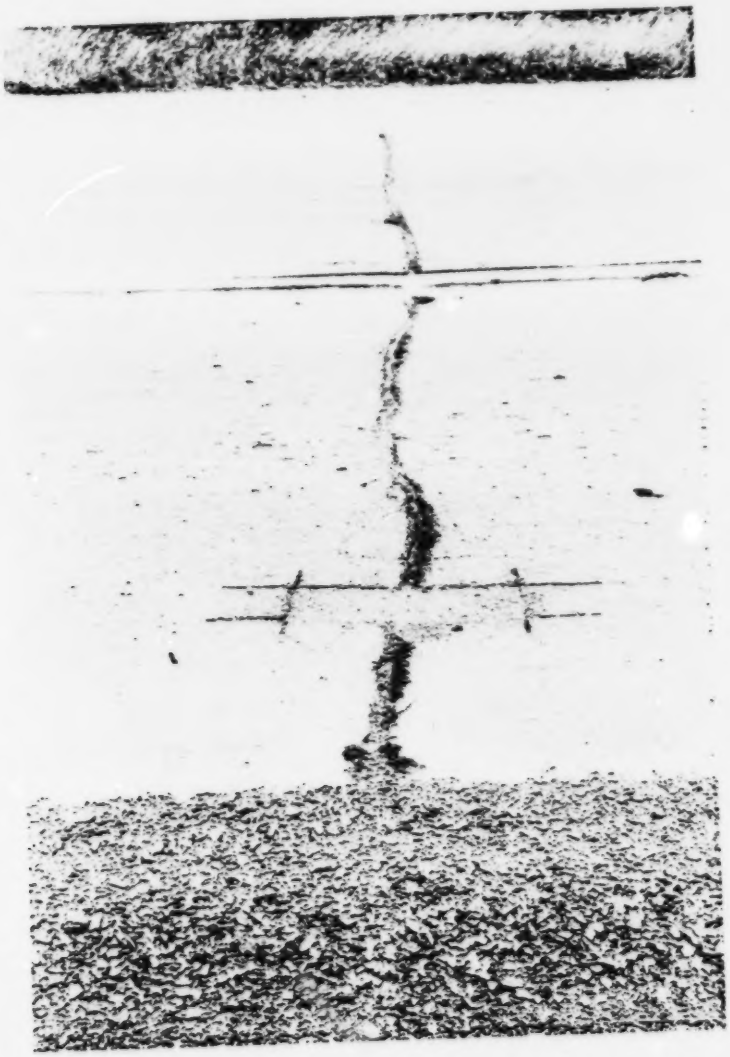


Figure 2/ Full width transverse crack, Hwy. 56, Section 2 (75 mm untreated OGDL)

Crack begins to alligator near the centreline. Backfilled area after cutting a 600 x 25 mm trench is noticeable.

Figure 3/ Area of extensive block cracking, Hwy. 56, Section 4 (150 mm untreated OGDL)

The area is on a vertical sag curve and superelevated.

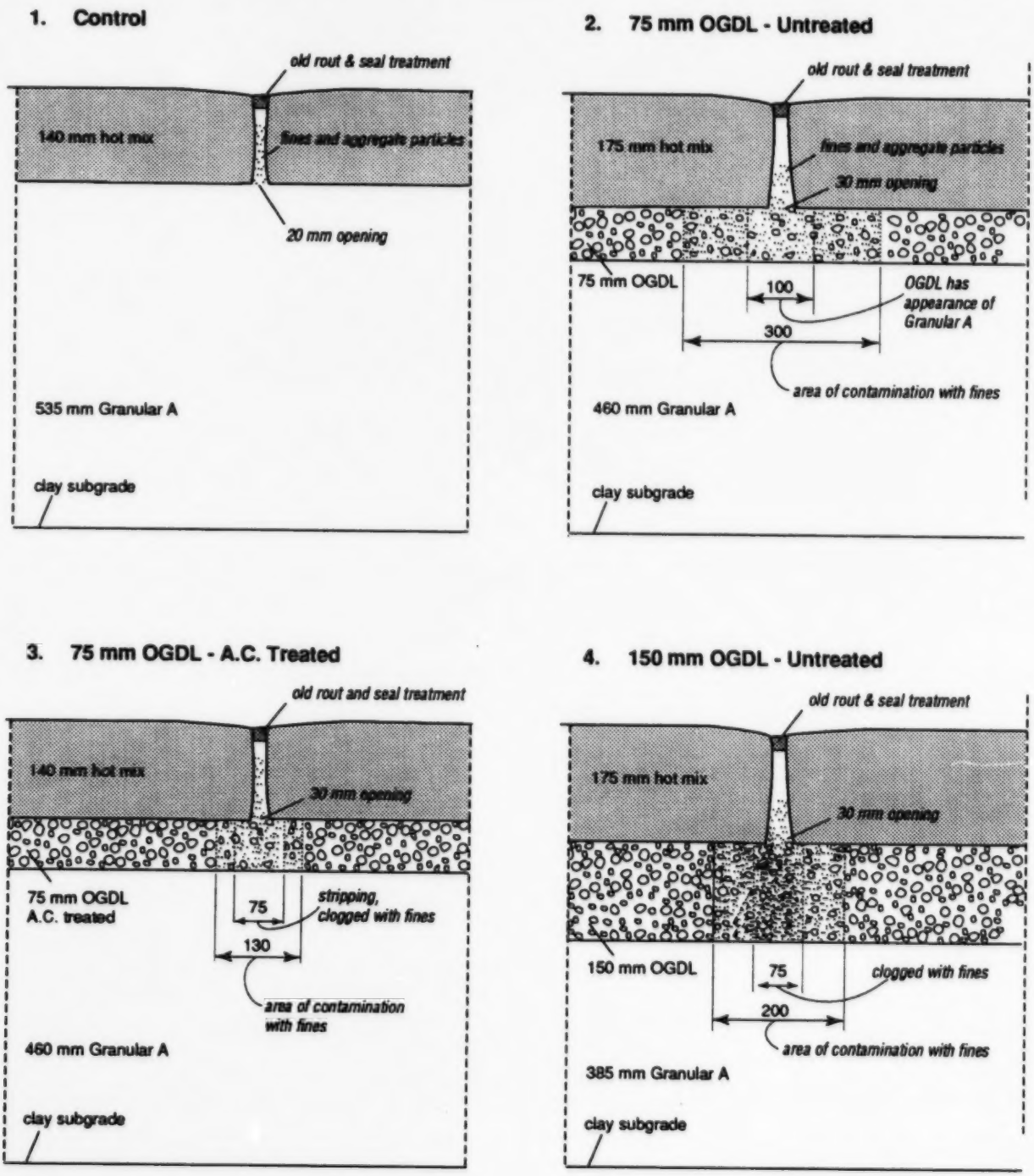


Figure 4/ Typical condition of full transverse cracks, Hwy. 56

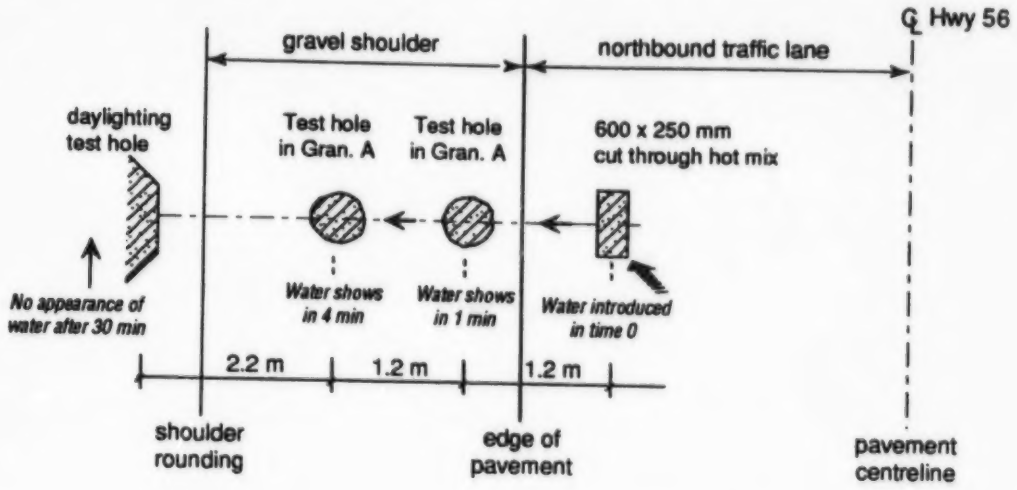


Figure 5/ Investigation of crossfall drainage, Hwy 56., Section 3

SECTION 1

- 305 mm plain jointed PCC slab
- silty clay subgrade

+ partially paved hot mix shoulder

SECTION 2

- 203 mm plain jointed PCC slab
- 100 mm open graded drainage layer
- silty clay subgrade

+ partially paved hot mix shoulder

SECTION 3

- 178 mm plain jointed PCC slab
- 127 mm lean concrete base
- silty clay subgrade

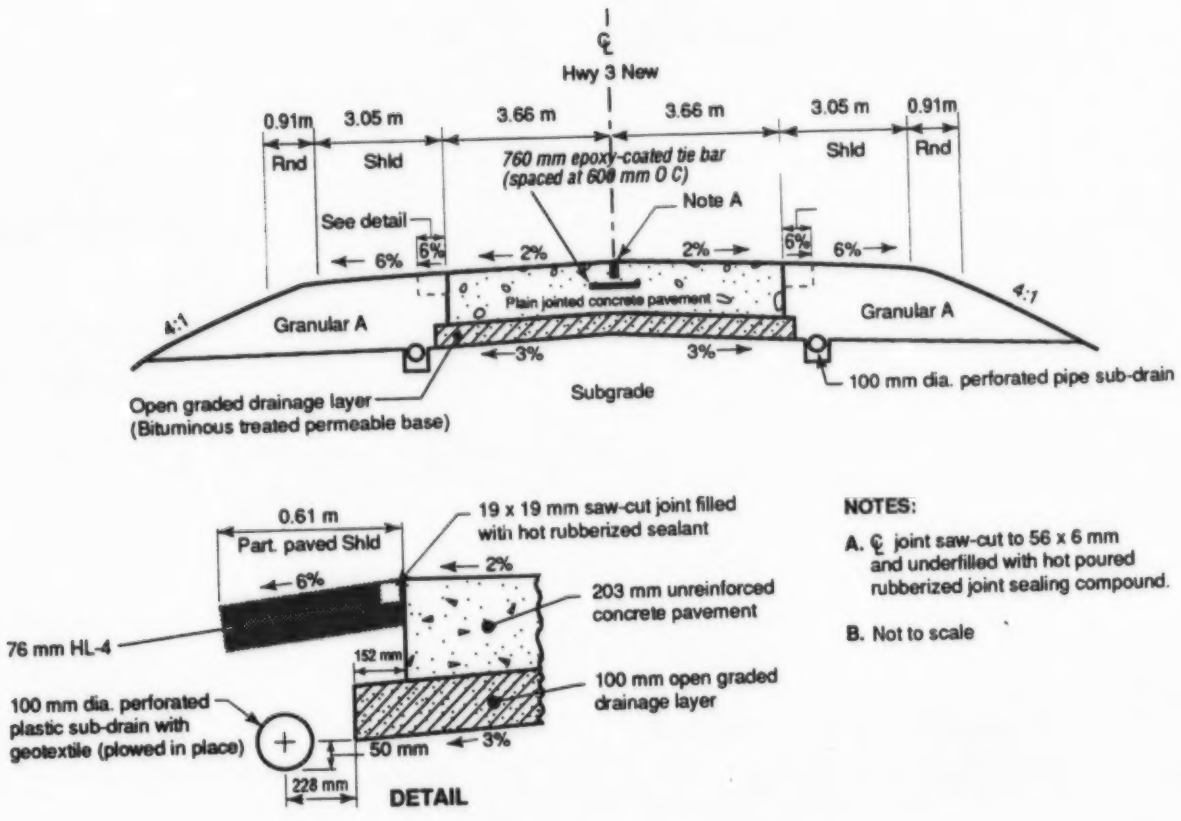
+ partially paved PCC shoulder

SECTION 4

- 203 mm plain jointed PCC slab
- 127 mm lean concrete base
- silty clay subgrade

+ partially paved PCC shoulder

Figure 6/ Design of four experimental PCC sections on Hwy. 3N



NOTES:

A. ℄ joint saw-cut to 56 x 6 mm and underfilled with hot poured rubberized joint sealing compound.

B. Not to scale

Figure 7/ OGDL pavement test section on Hwy. 3N

Source: Reference 8

Figure 8/ 150 mm core obtained far from cracks or joints, Hwy. 3N
OGDL material is basically in one place and is partially bonded to the surface layer.

Figure 9/ 150 mm core obtained at transverse joint, Hwy. 3N
OGDL material is a loose mixture of stripped OGDL aggregate particles and the subgrade soil.

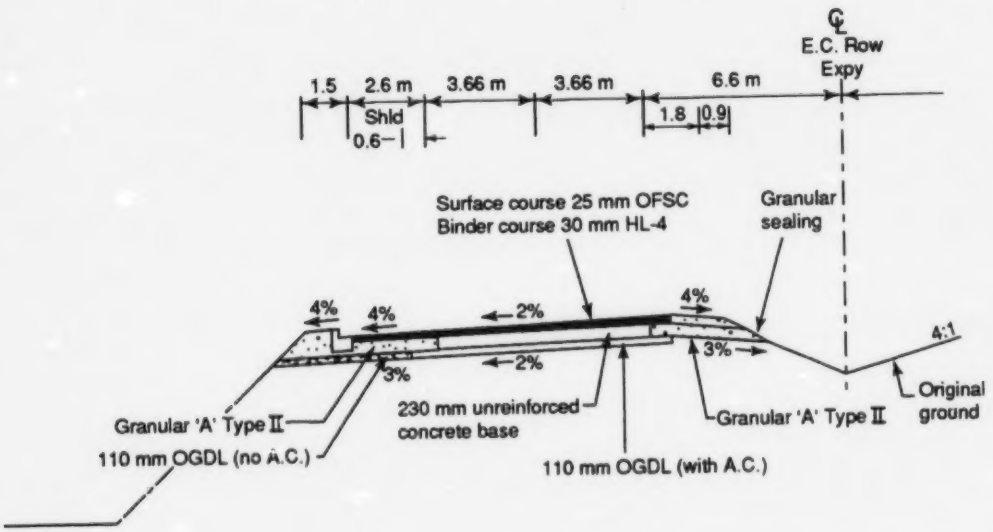


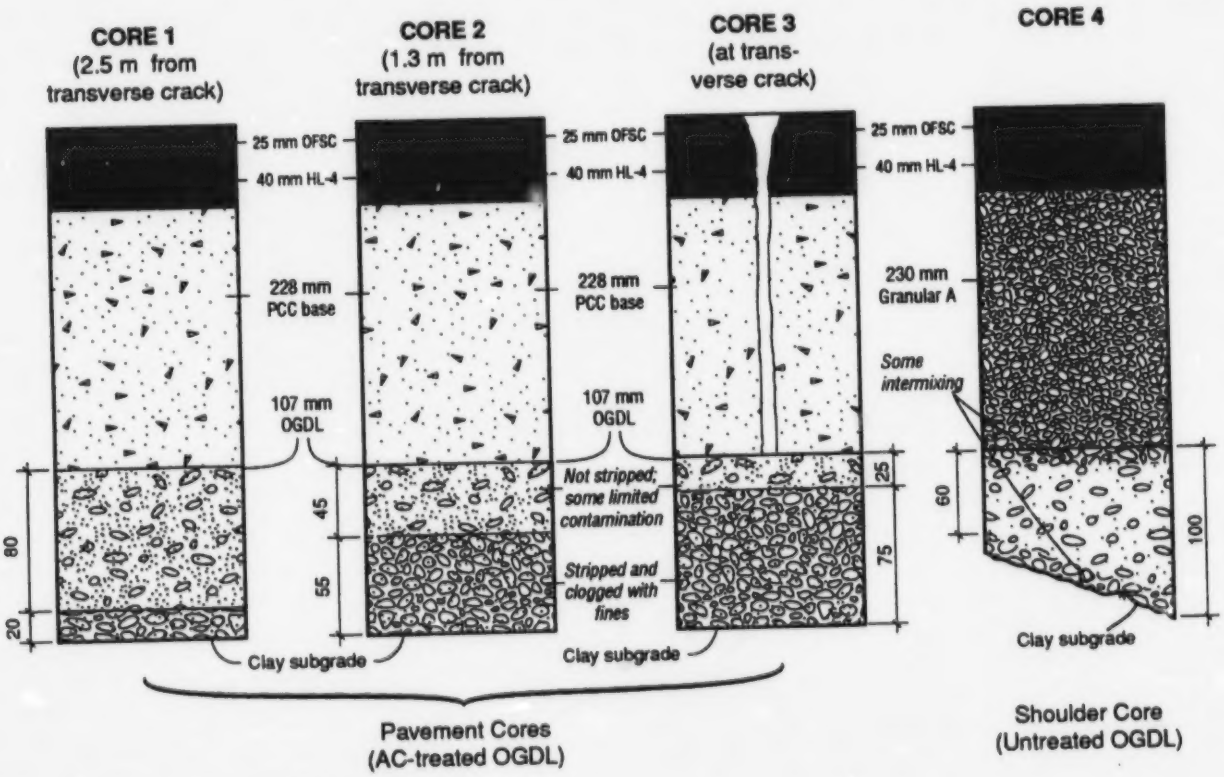
Figure 10/ OGDL section on E.C. Row Expressway

Source: Contract Drawings 87 - 37

Figure 11/ Coring of a transverse crack, E.C. Row Expressway

Westbound truck lane approaching Dominion Blvd. overpass, right wheel path.

Note incipient spalling and ravelling of the crack. White colloidal mixture of water and PCC particles ejected from the spinning drill-bit readily re-enters the unsealed transverse crack.



All dimensions in mm unless otherwise specified

Figure 12/ Condition of OGDL material, E.C. Row Expressway

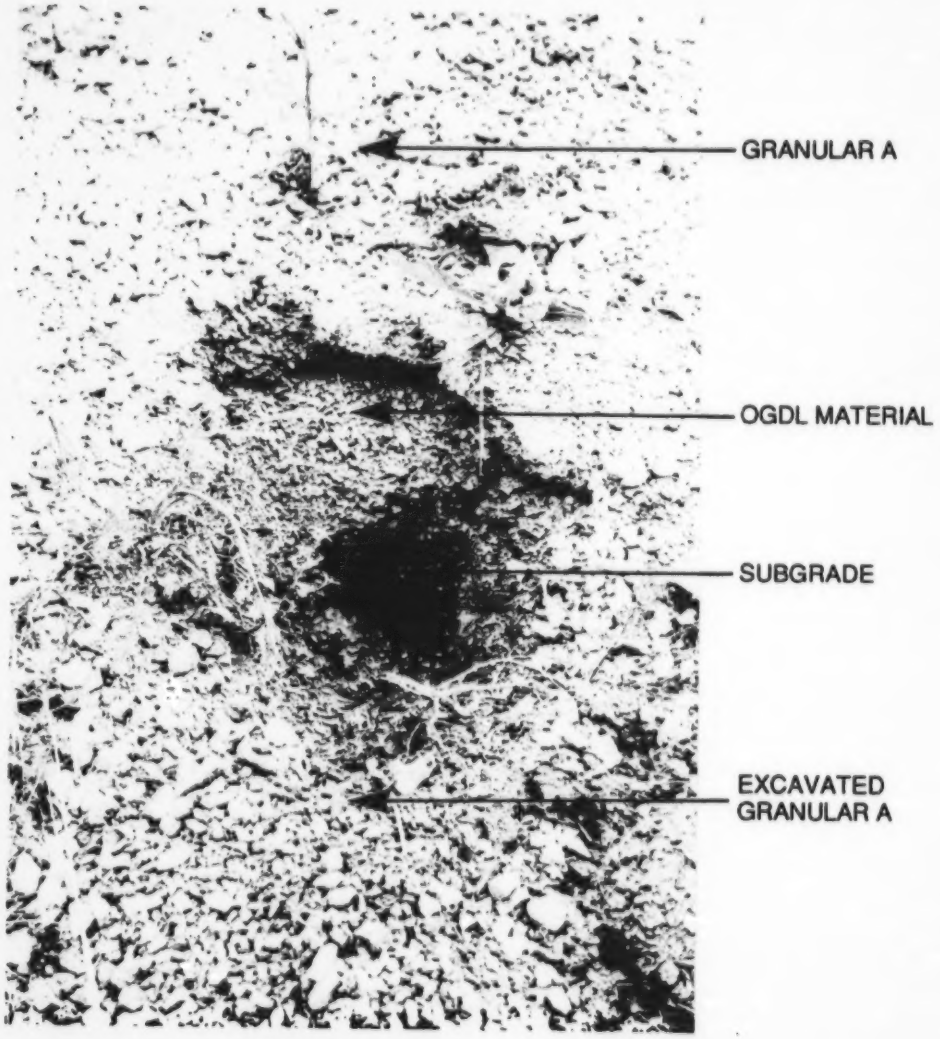
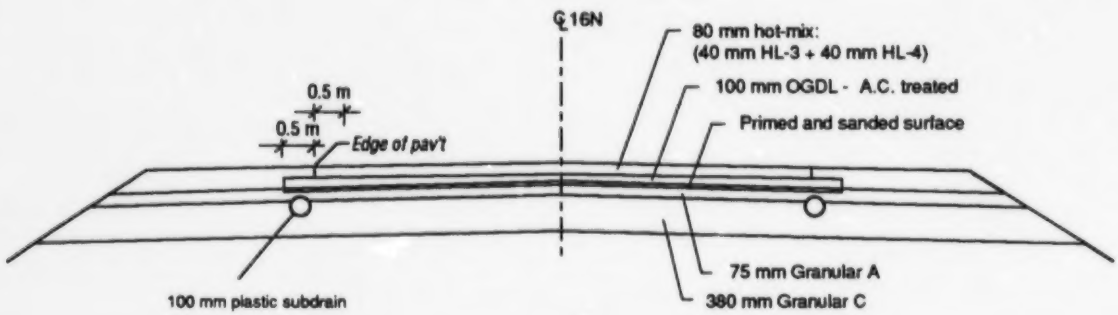


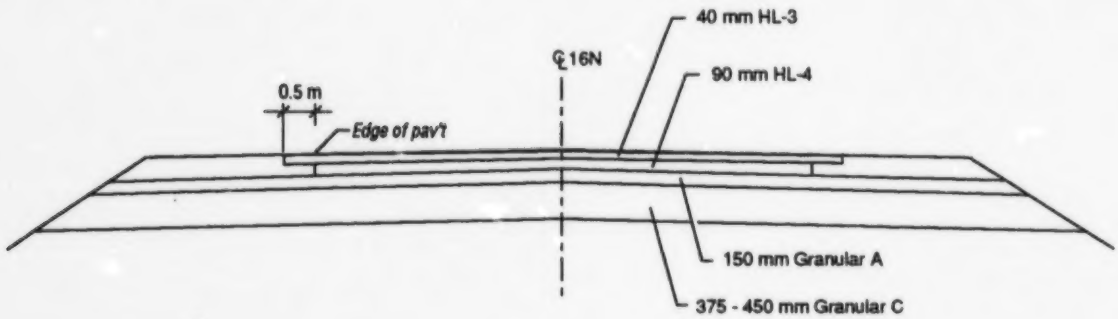
Figure 13/ Appearance of OGDL material at the daylighting test hole at ditch slope

Note sparse vegetation on the slope covered mostly by segregated Granular A material. Subgrade soil below the OGDL material is saturated.

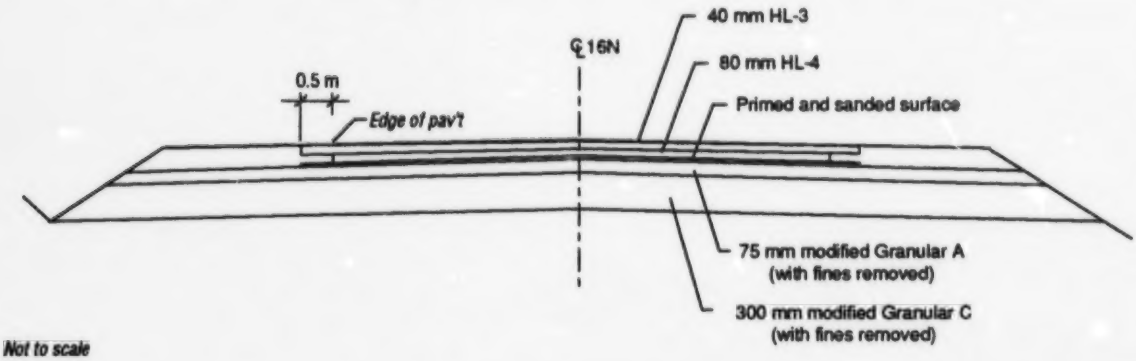
OGDL Section



Conventional Section



Modified Granular Section



Not to scale

Figure 14/ Typical sections for three pavement test sites, Hwy. 16N

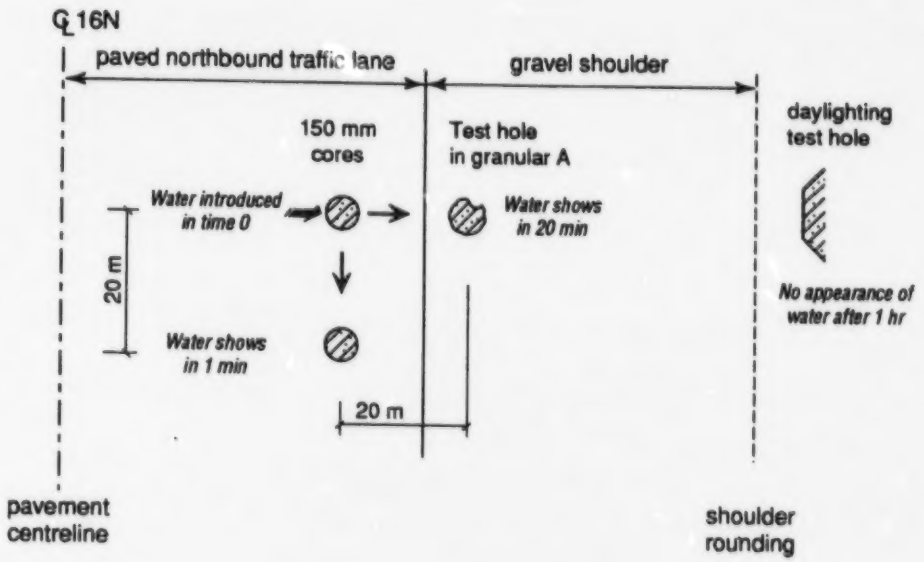


Figure 15/ Investigation of crossfall drainage, Hwy. 16N

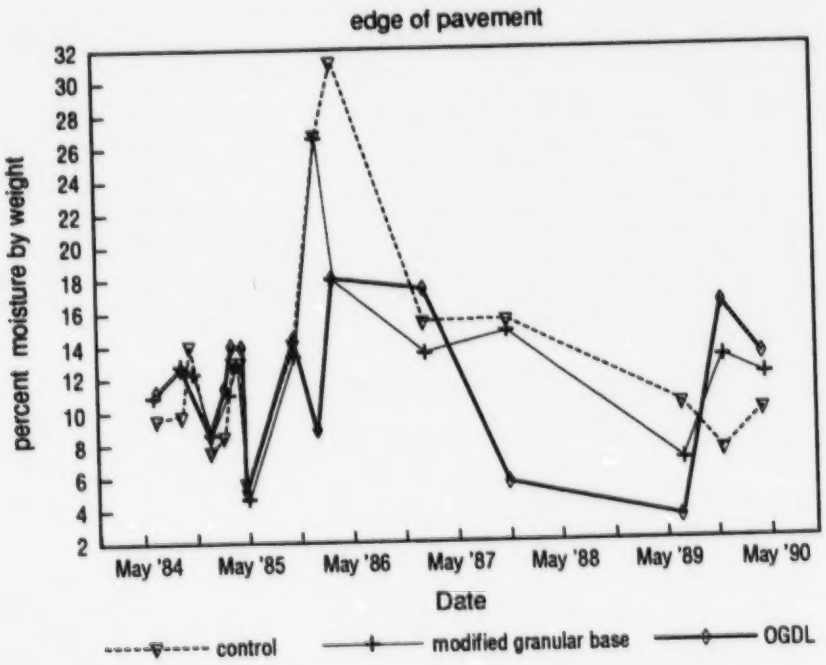


Figure 16/ Subgrade moisture content, edge of pavement, Hwy. 16N

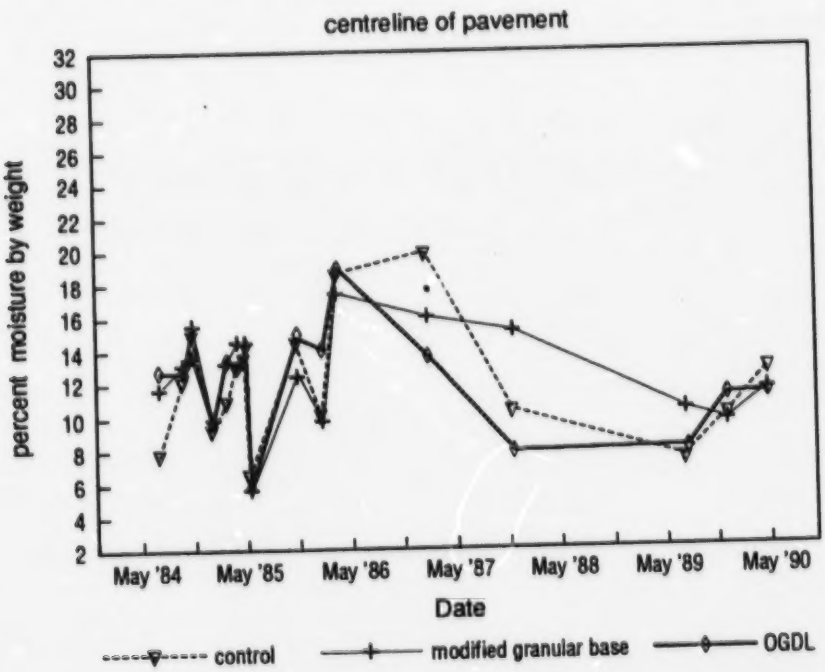


Figure 17/ Subgrade moisture content, centreline of northbound lane, Hwy. 16N

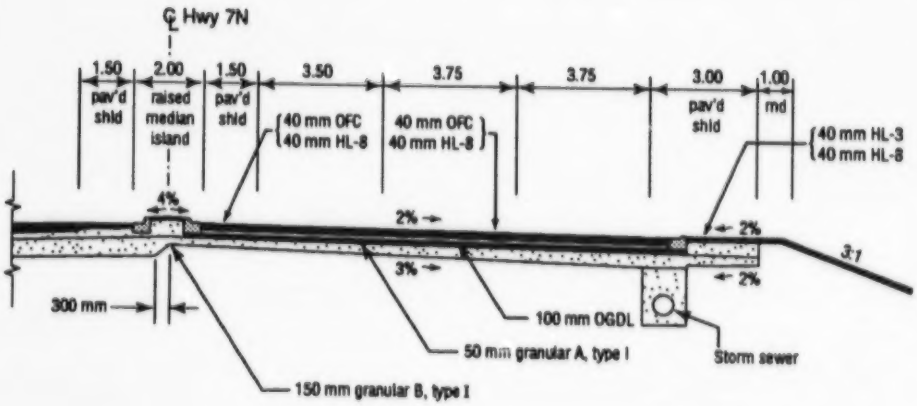
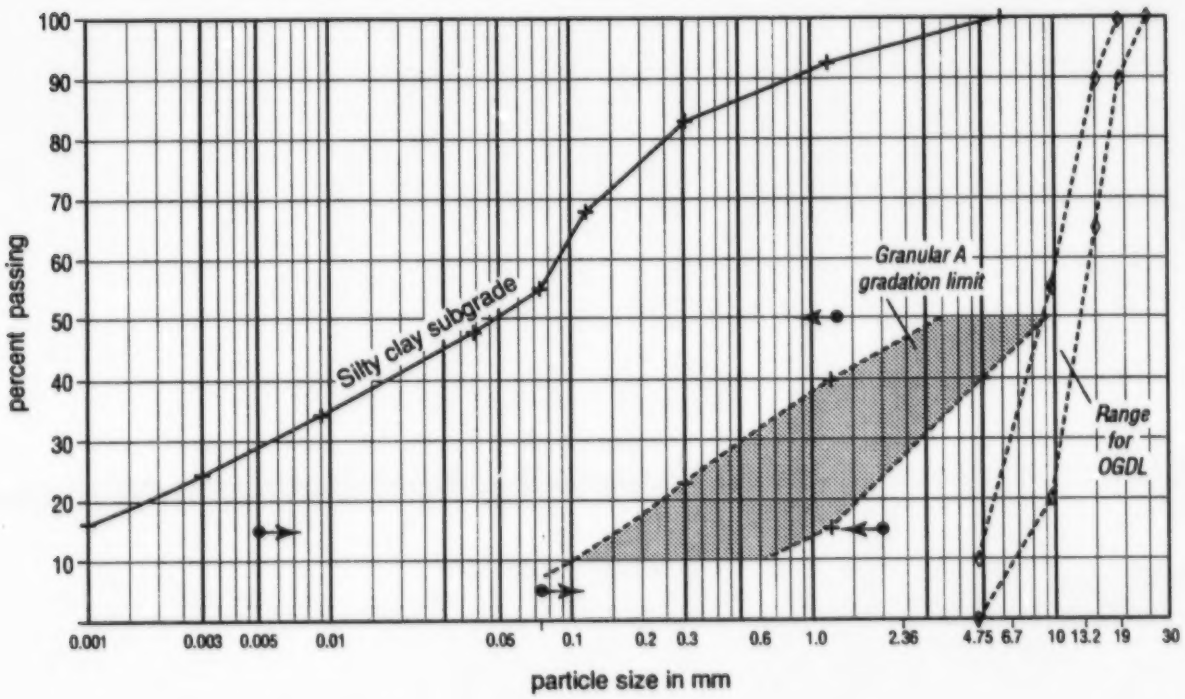
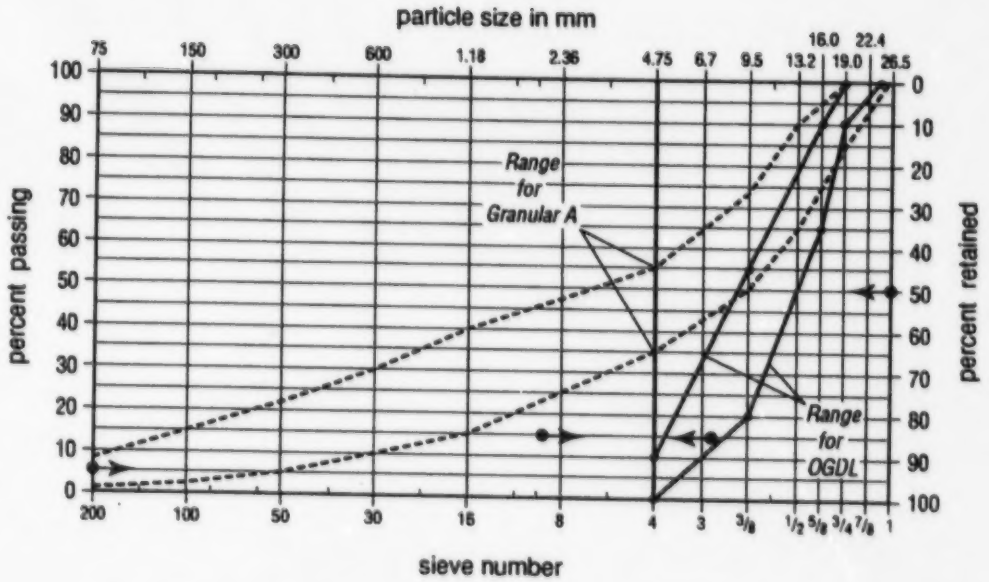


Figure 18/ OGDL section on Hwy. 7N
Source: Contract 84-85



Note: Filter gradation should be within the limits indicated by arrows ●→

Figure 19/ Filter requirements to protect OGDL from intrusion of fines from subgrade



Note: Filter gradation should be within the limits indicated by arrows ●→

Figure 20/ Filter requirements to protect OGDL from intrusion of fines from Granular A